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# Regional-Scale Downscaling of Typhoon Hazards under Changing Climate


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京都大学
KYOTO UNIVERSITY

# Assessing typhoon hazards at regional-scales

Typhoon hazard is one of the major meteorological hazards in the western North Pacific region.

- Coastal regions/island regions – Storm surge, high wave
- Land regions – Heavy rainfall/high wind, often topographically induced

Hazards depend on regional geographical characteristics.

- Complex topography, climatology

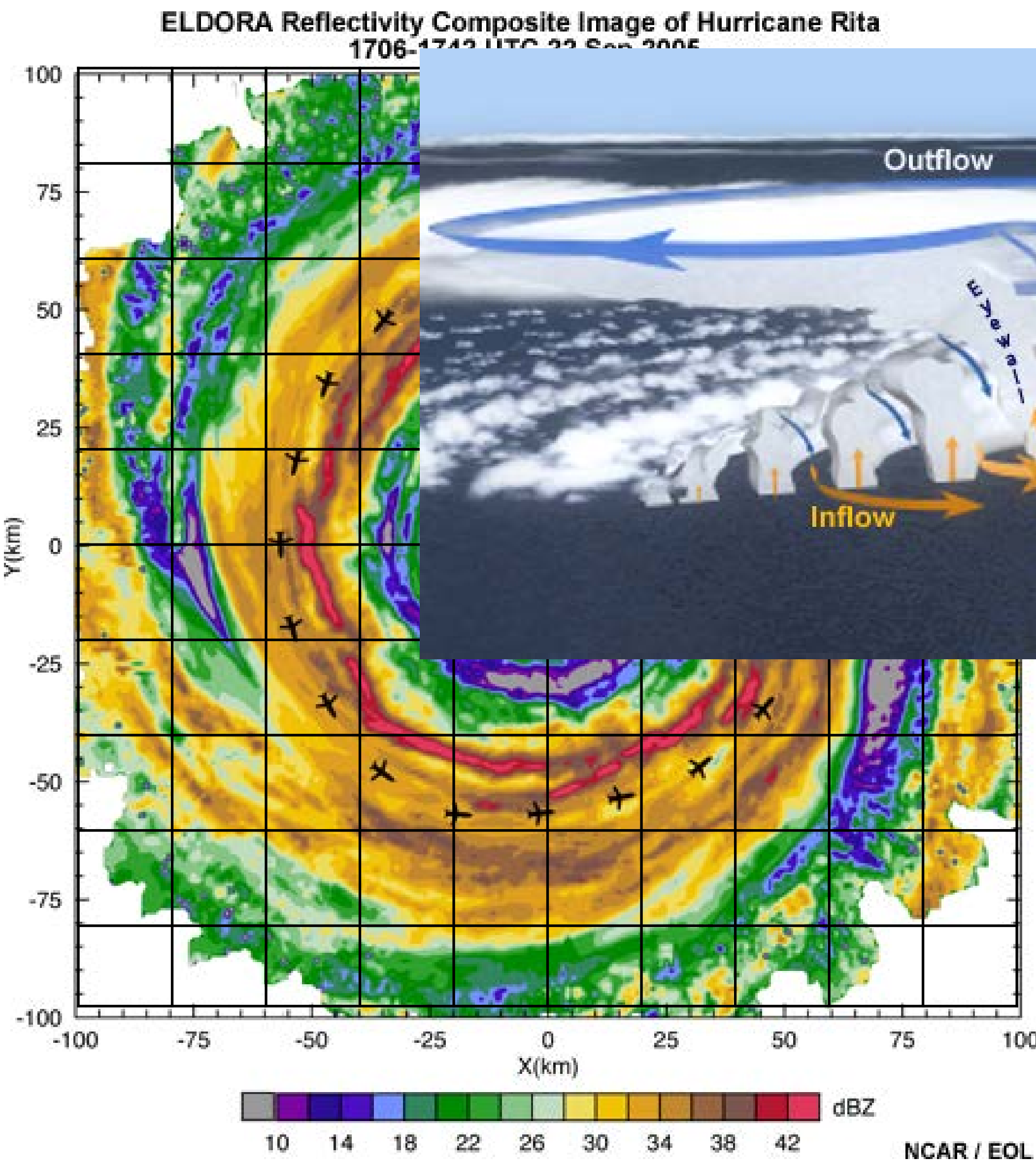
Quantitative assessment on the impacts from hazards is required for disaster prevention and mitigation.

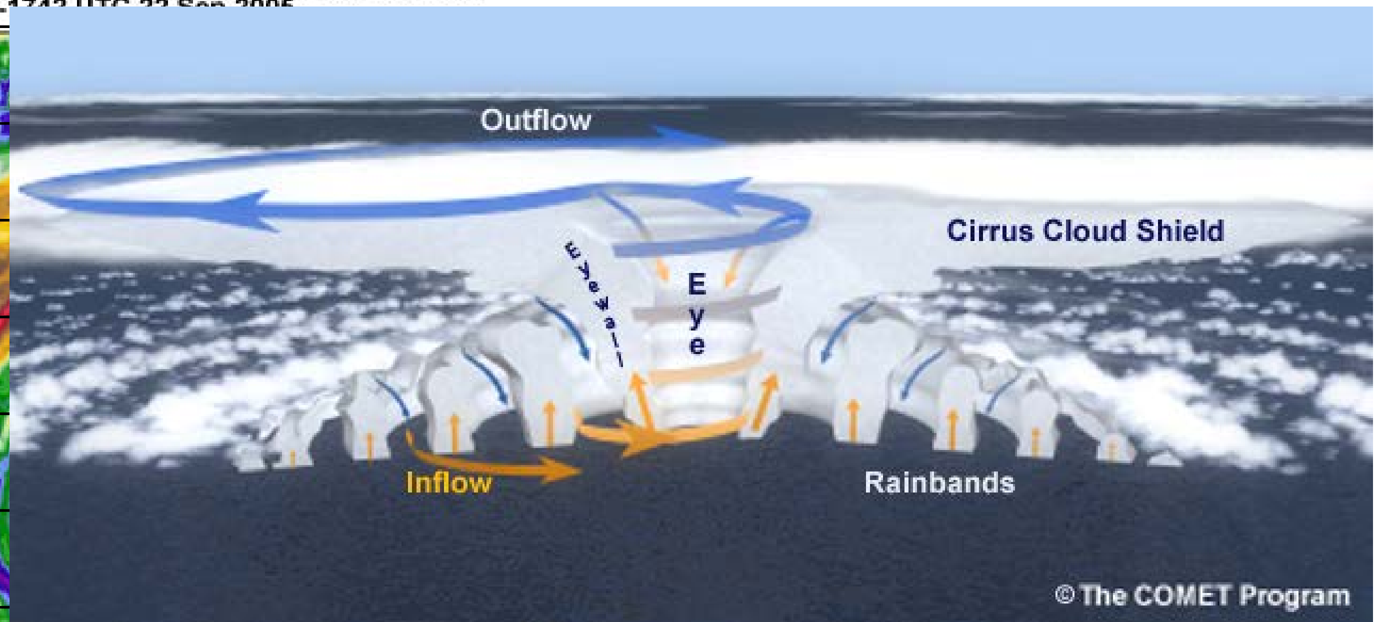
- Amount of rainfall, wind speed – Warning, Controlling flood, inundation, outside operation/activity

Assessment of typhoon impacts under global warming is important for disaster mitigation and adaptation planning.

- Changes in the severity of category-5 tropical cyclones and the resulting hazards under global warming

# Typhoon has a meso-$\alpha/\beta/\gamma$-scale structure




200 km

200 km

Analysis requires a multi-scale point of view.

# How to assess the impacts of typhoon hazards?

- Hazards can be assessed by considering worst-class scenarios.
  - Past disaster-spawning cases are regarded as a baseline for the hazard assessment
- Downscaling experiments with a regional numerical weather prediction model are vital for quantitatively representing convective-scale processes.
  - Cloud-resolving/permitting resolution
- Effective use of climate prediction experiments is important.
  - High-resolution GCM data
  - Pseudo-global warming (PGW) experiments: worst-case scenario under global warming

## Downscaling experiments for worst-class typhoons

Typhoon Haiyan (2013)

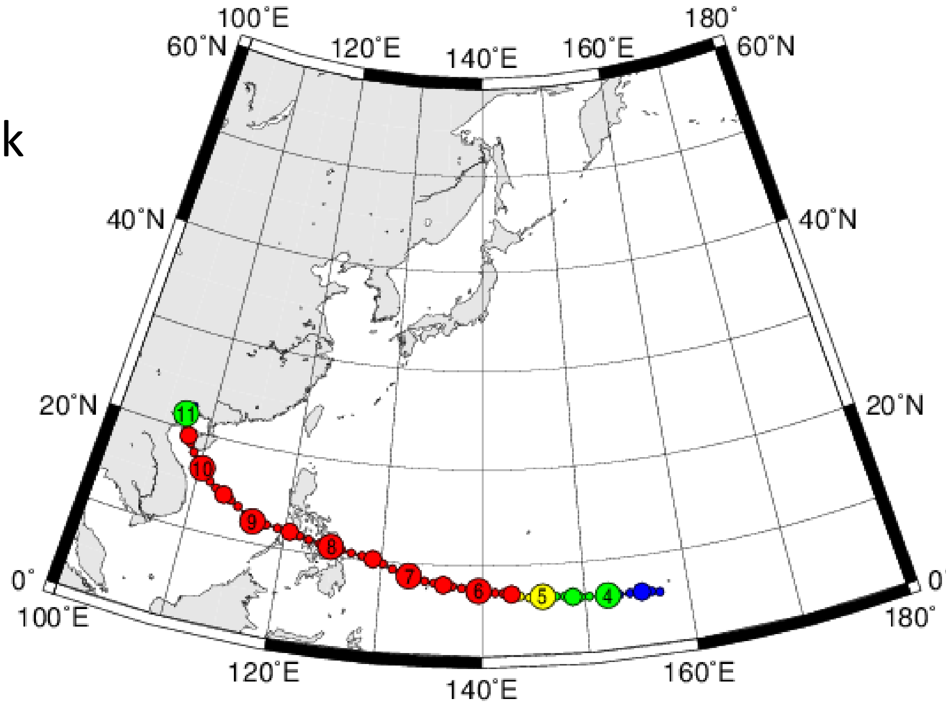
Typhoon Vera (1959) (Isewan Typhoon)

Typhoon Songda (2004)

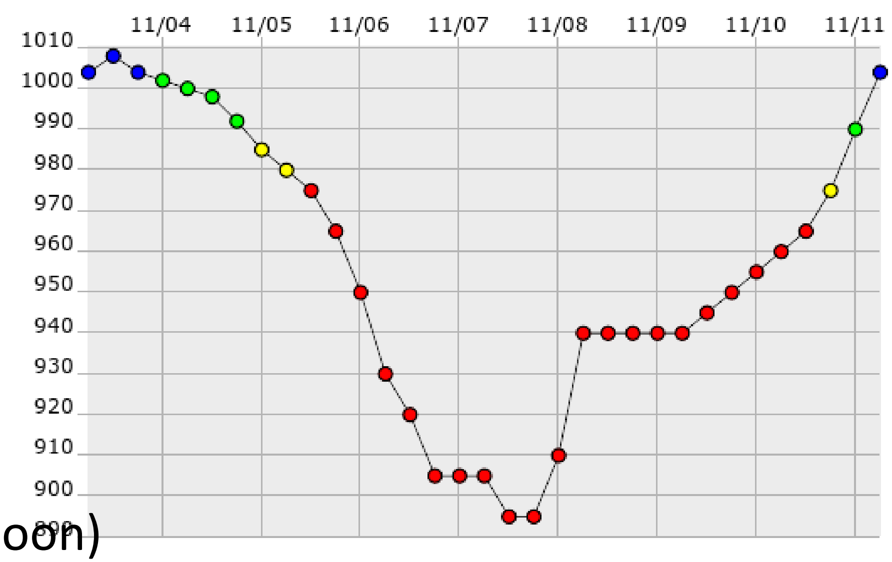
DPRI-KU

# Super Typhoon Haiyan (2013)

Track




Central pressure




<u>Maximum intensity</u>

Central pressure:
895 hPa

Max wind speed: 65 m/s

(best track)

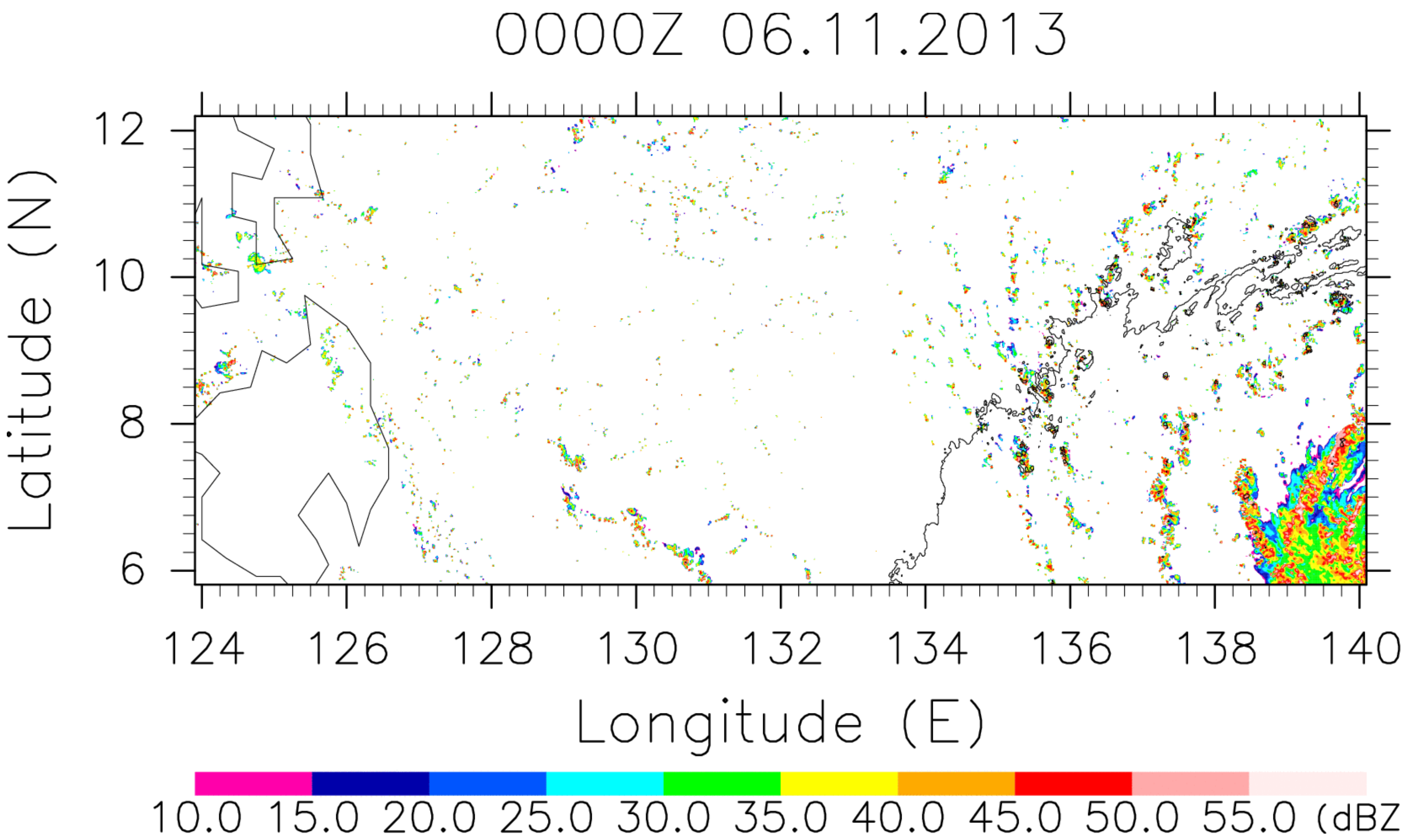
(From Digital Typhoon)

# Model and experimental settings

- Model: WRF/ARW Version 3.3.1
- Initial and boundary conditions:
  - Atmosphere: NCEP Final Analysis (FNL)
  - SST: NCEP FNL or JMA MGDSST
- Domain & resolution: 3 km/1 km
  - Domain 1 (3 km): 4000 km x 2000 km
  - Domain 2 (1 km): 2000 km x 700 km, and etc.
  - Vertical levels: 56
  - Model top: 20 hPa
- Simulation period:
  - 0000 UTC 5 Nov – 0000 UTC 10 Nov 2013

# Typhoon Haiyan (2013): Simulation with WRF

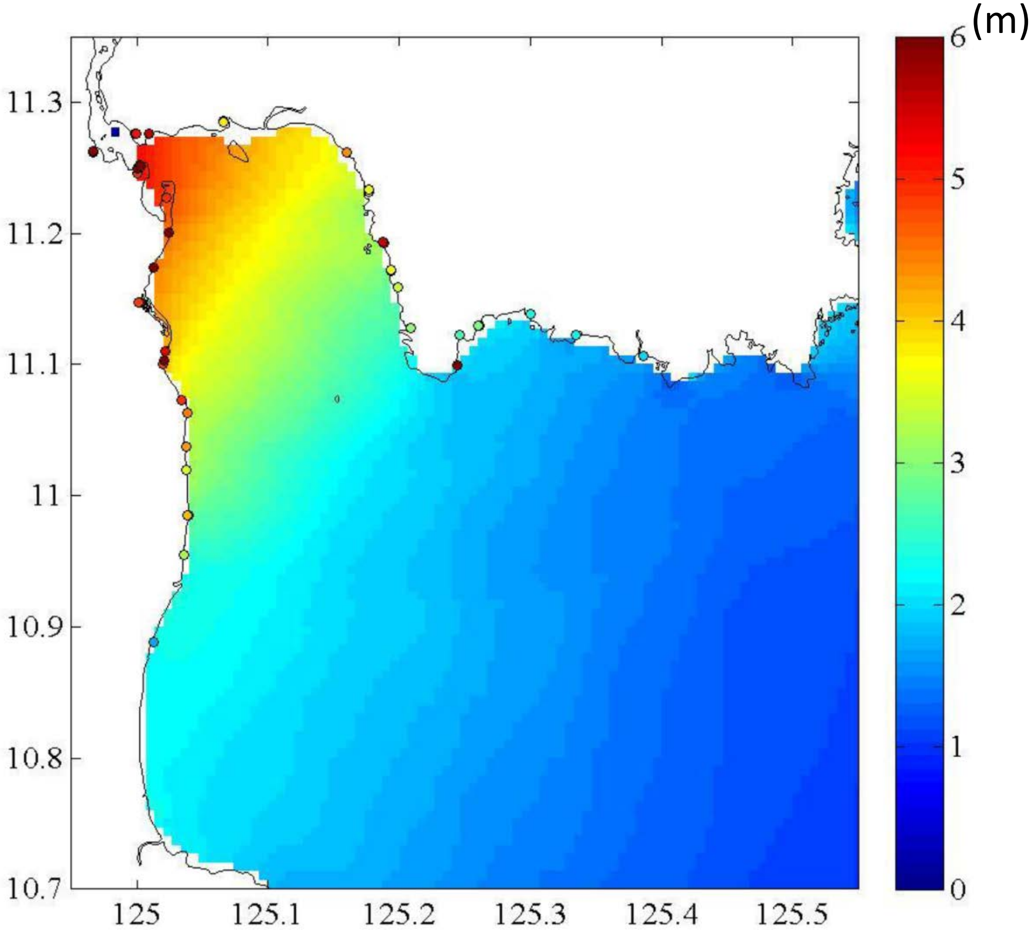
Regional simulation with the Weather Research and Forecasting (WRF) model at 1-km resolution



# Simulation of storm surge in Leyte Gulf

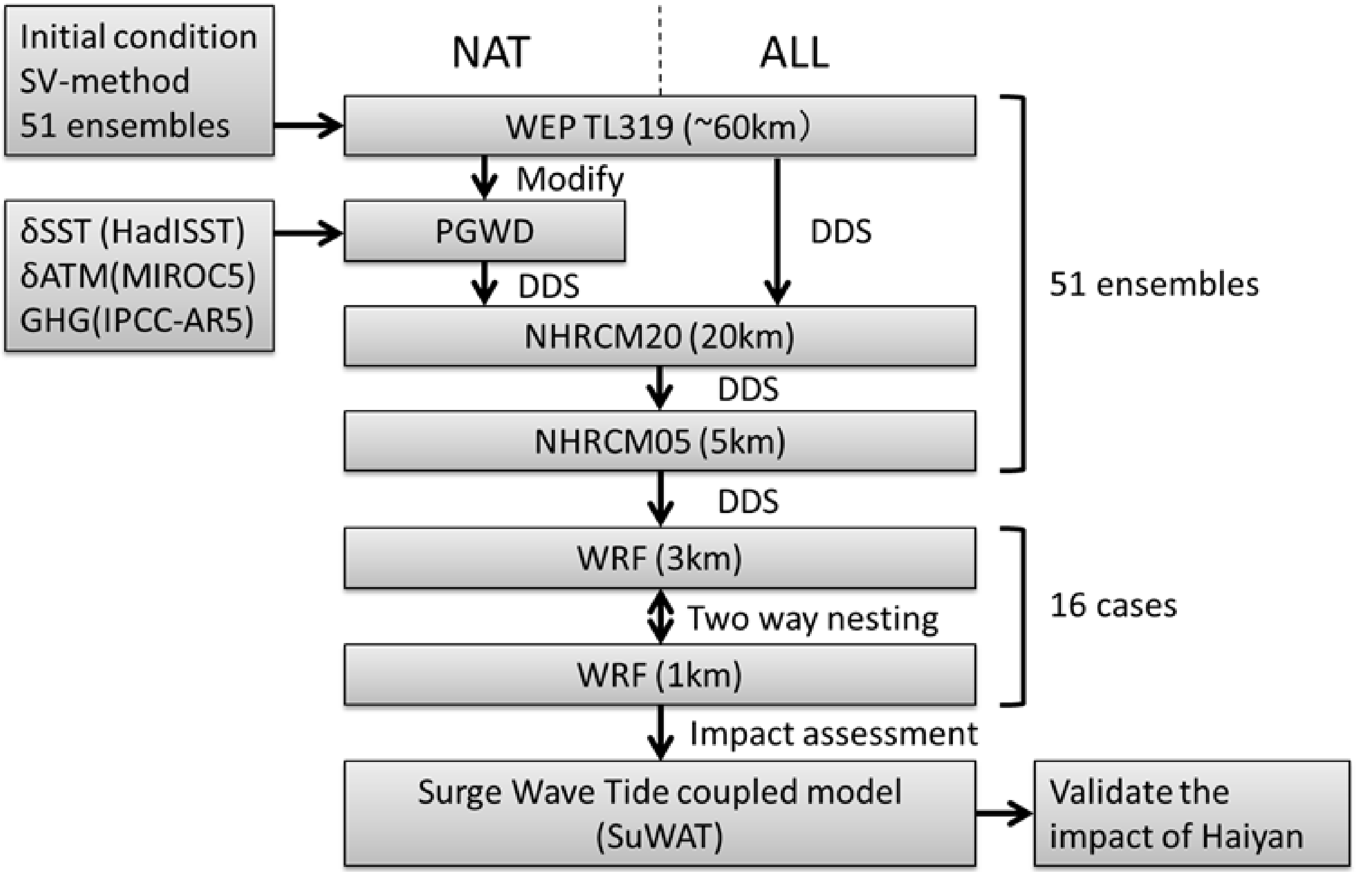
Maximum water surface elevation with the use of the WRF outputs

Circle points indicate the measurements.




(Mori et al. 2014)

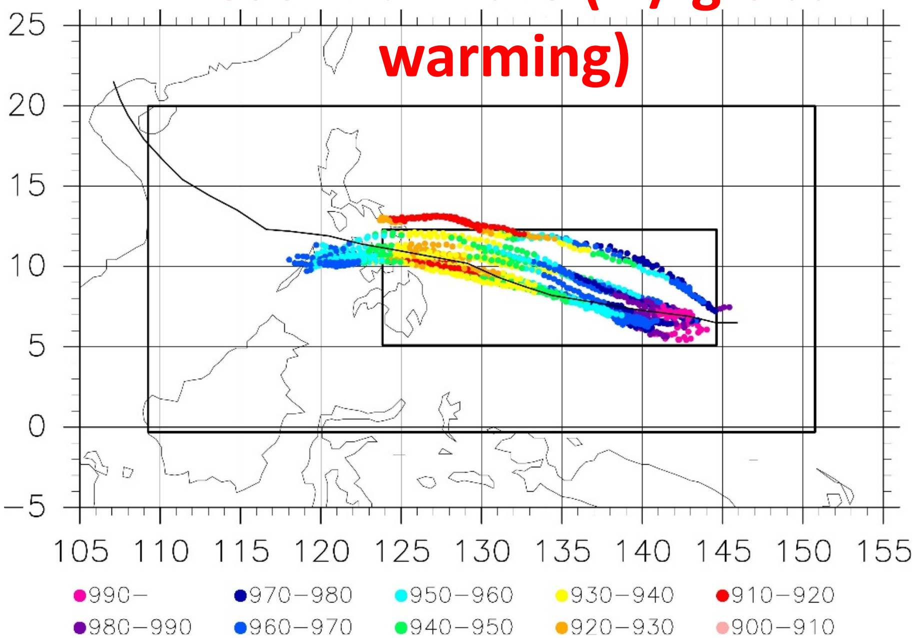
# Effects of climate change on worst storm surge



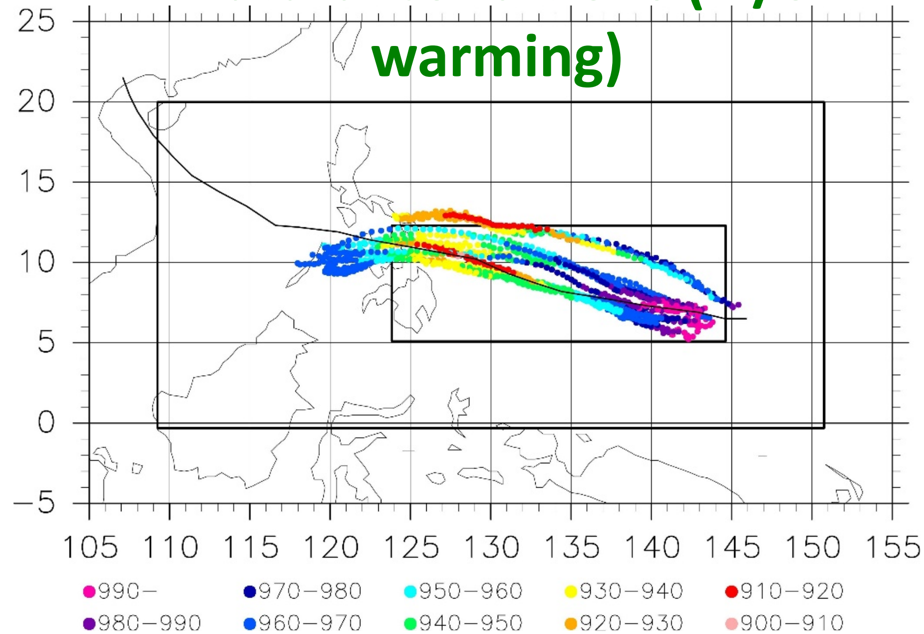

Takayabu, I., K. Hibino, H. Sasaki, H. Shiogama, N. Mori, Y. Shibutani, T. Takemi, 2015: Climate change effects on the worst-case storm surge: a case study of Typhoon Haiyan. *Env. Res. Lett.*, **10**, 064011

# Intensity of tropical cyclones

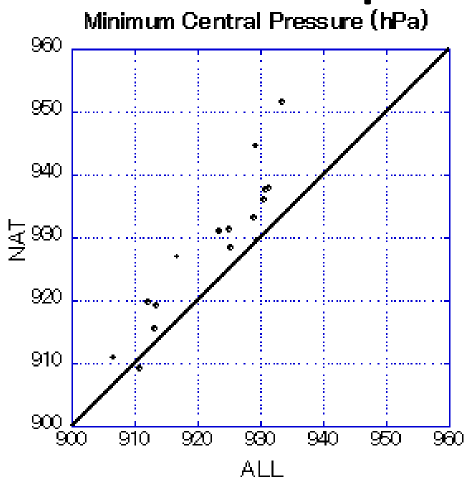
## Present climate (w/ global warming)



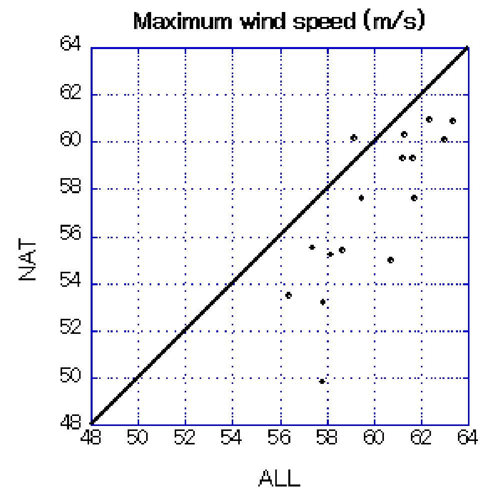

## Natural conditions (w/o warming)




## Minimum central pressure

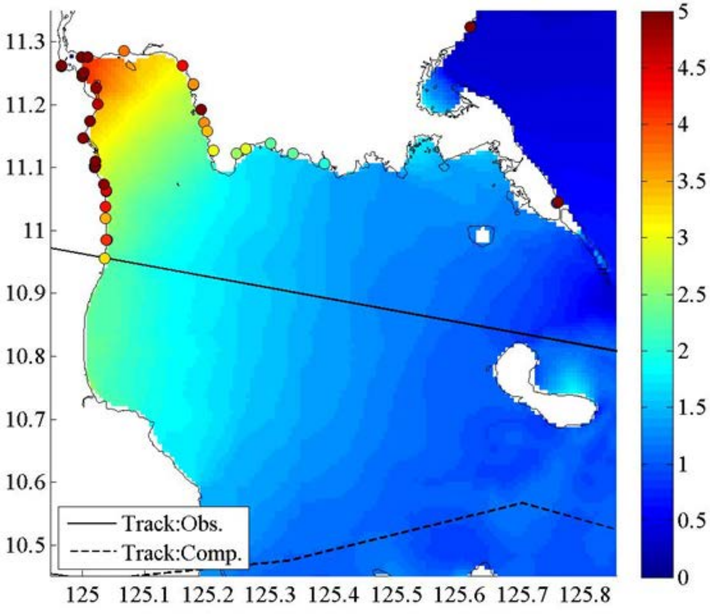


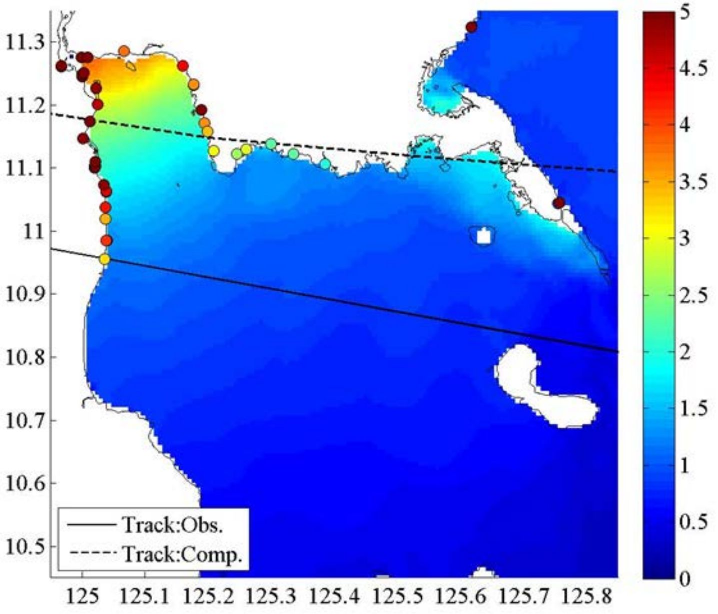

## Maximum wind speed




Takayabu, I., et al. 2015, *Env. Res. Lett.*, **10**, 064011

# Storm surge




Increase the water level by 10—20 % due to global warming for the worst-case storm surge from a Haiyan-class typhoon

Takayabu, I., et al. 2015, *Env. Res. Lett.*, **10**, 064011

# Typhoon Vera (1959): “Isewan Typhoon”

- Downscaling experiments with the WRF model
  - Initial and boundary conditions: JRA-55
- Typhoon Vera (1959) “Isewan Typhoon”: September 1959
  - Minimum central pressure: 895 hPa
  - Storm surge/high waves in the Ise Bay
  - River discharge in the Yodo River basin
  - The highest resolution of the nested domains: 1km
- Assessing the impacts of global warming
  - Pseudo-global warming (PGW) experiments
    - † Climate change increment between future and present climate simulated by MRI-AGCM3.2S

# Pseudo-global warming experiment

## Global warming increment

Future changes in temperature, pressure, sea surface temperature from GCM climate prediction data

Increment = (GCM future climate) – (GCM present climate)

## Past analysis

Long-term reanalysis dataset: JRA-55 (available from 1958)

## Add global warming increment to past analysis fields

Example: Vera-class extreme typhoon under global warming

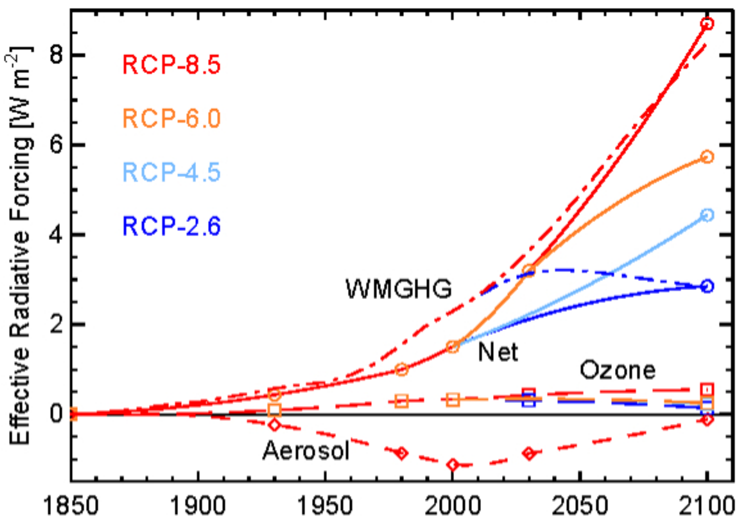
(Pseudo-global warming climate)

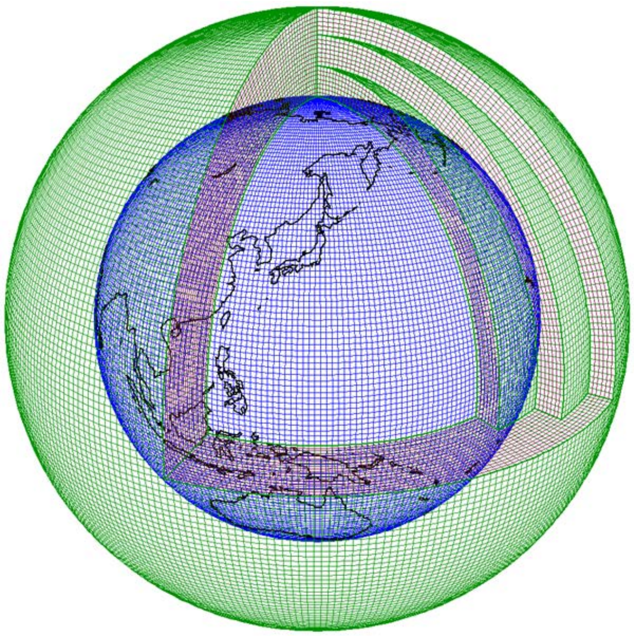
= (Sep 1959 reanalysis) + (Sep monthly mean GW increment)

# Climate prediction data

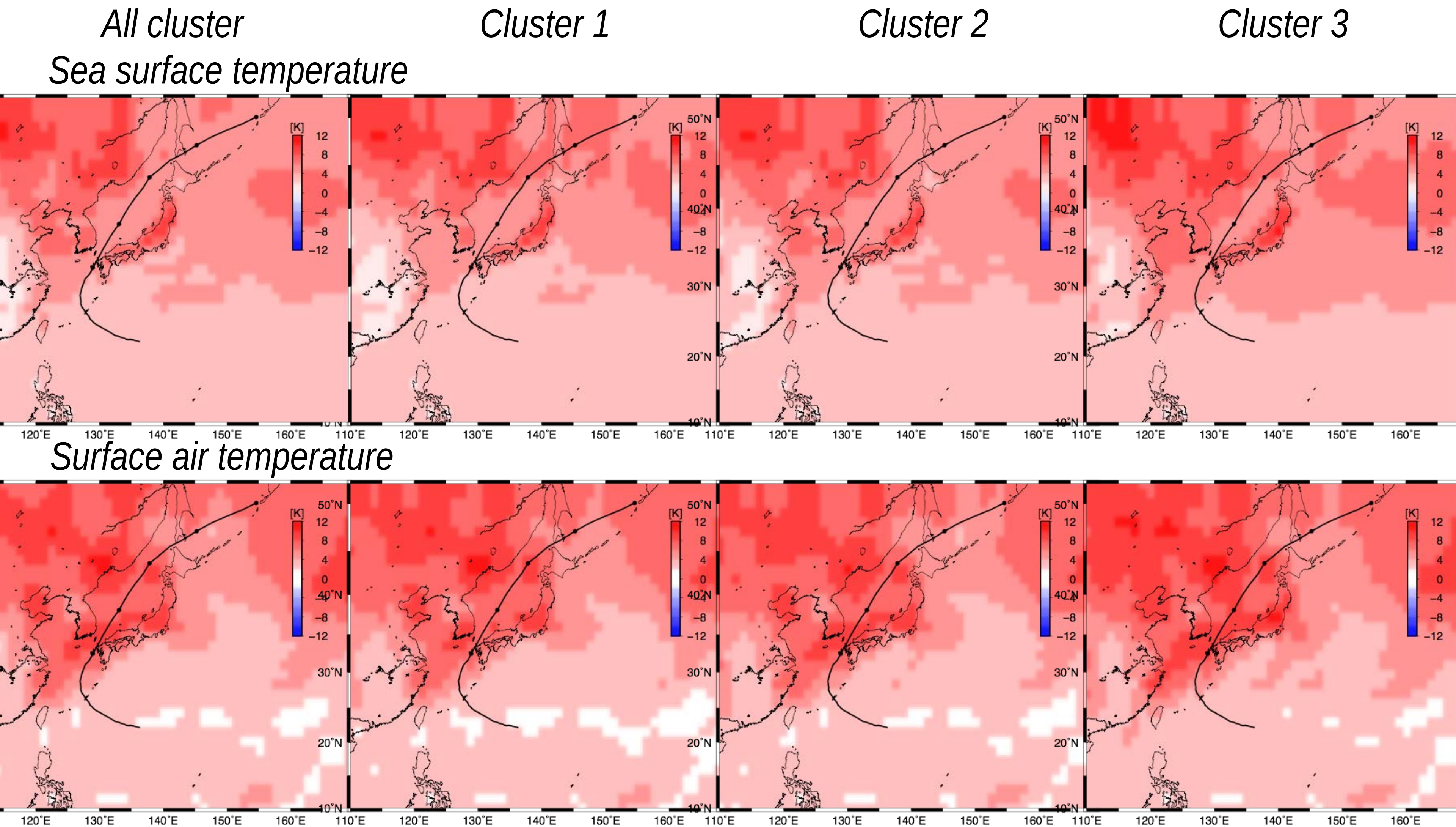
- Climate simulation data by JMA/MRI-AGCM3.2 (Atmospheric General Circulation Model Version 3.2)
  - Present climate: 1979-2003
  - Future climate: 2075-2099 under various Representative Concentration Pathways (RPCs) (CO2 emission scenario)
  - Spatial resolution: 20 km and 60 km

**Effective radiative forcing corresponding to CO2 increase**



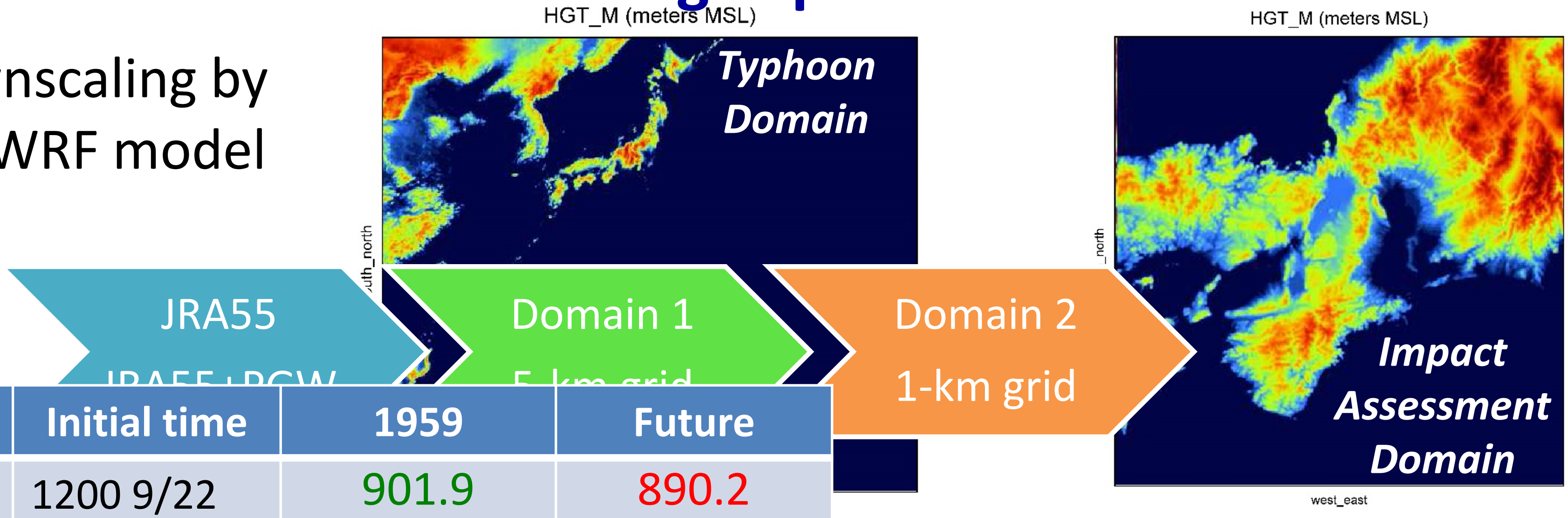



# Global warming increment in September

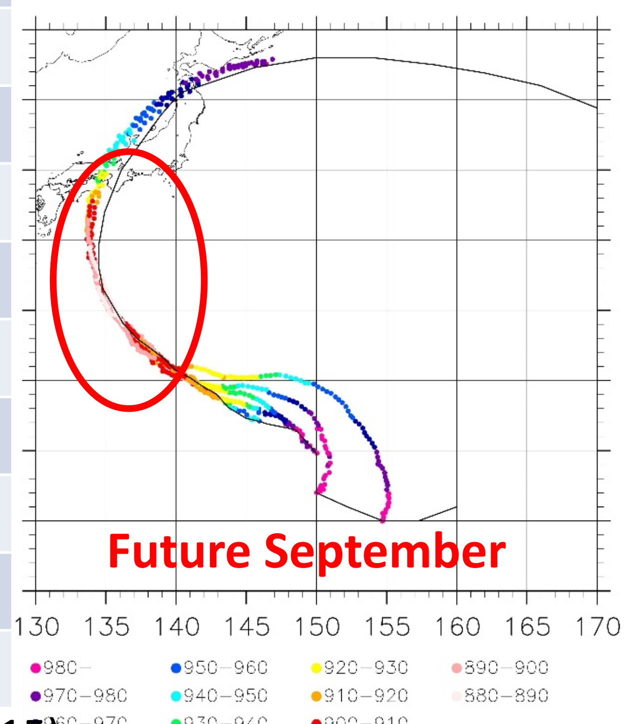


# Downscaling experiments

Downscaling by the WRF model




| | Initial time | 1959 | Future |
|---|---|---|---|
| MCP (hPa) | 1200 9/22 | 901.9 | 890.2 |
| | 0000 9/22 | 901.8 | 893.0 |
| | 1200 9/21 | 899.5 | 898.1 |
| | 0000 9/21 | 904.9 | 886.0 |
| | 1200 9/20 | 909.0 | 879.4 |
| MWS (m/s) | 1200 9/22 | 58.3 | 65.3 |
| | 0000 9/22 | 58.4 | 65.5 |
| | 1200 9/21 | 57.9 | 66.2 |
| | 0000 9/21 | 55.4 | 65.6 |
| | 1200 9/20 | 61.8 | 66.1 |



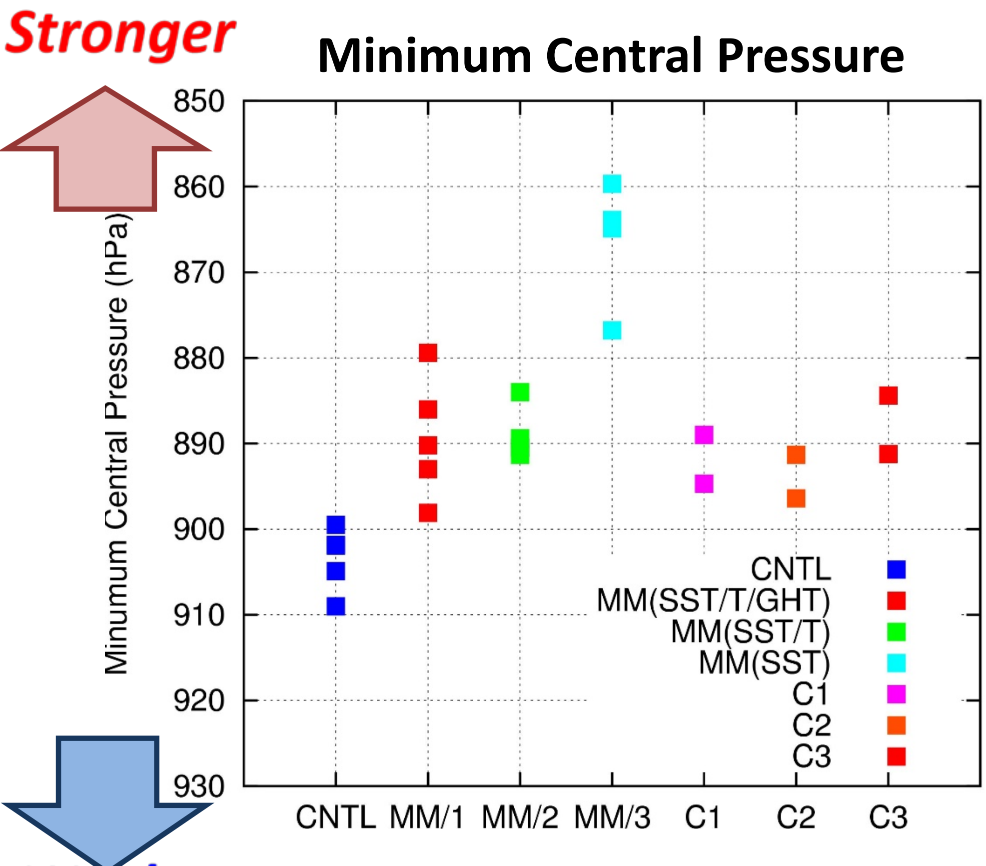

(Mori and Takemi 2015)

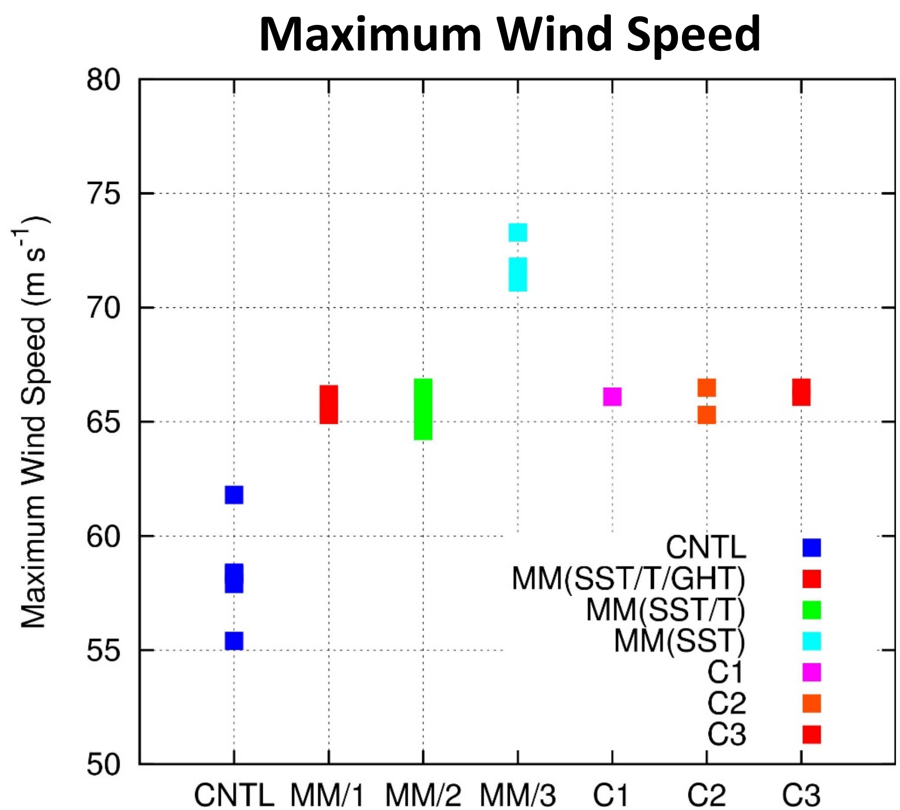
# Pseudo-global warming (PGW) experiments

- **CNTL**: Sep 1959 condition; initialized at 5 different times
- **PGW**: Four different SST conditions (Mizuta et al. 2014)
  - CMIP5 multi-model ensemble mean SST
  - Three SST patters from cluster analysis (Cluster 1, 2, and 3)

| | | Added vars | 9/22 12UT | 9/22 00UT | 9/21 12UT | 9/21 00UT | 9/20 12UT |
|---|---|---|---|---|---|---|---|
| 1959 Exp (CNTL) | | | case001 | case002 | case003 | case004 | case005 |
| Pseudo-global warming (PGW) | SST MM | SST, T, GHT | case101 | case102 | case103 | case104 | case105 |
| | | SST, T | case111 | case112 | case113 | case114 | case115 |
| | | SST | case121 | case122 | case123 | case124 | case125 |
| | SST C1 | SST, T, GHT | | case202 | | | |
| | | SST, T | case211 | | | | |
| | SST C2 | SST, T, GHT | | case302 | | | |
| | | SST, T | case311 | | | | |
| | SST C3 | SST, T, GHT | | case402 | | | |
| | | SST, T | case411 | | | | |

# Intensification of Isewan Typhoon under GW

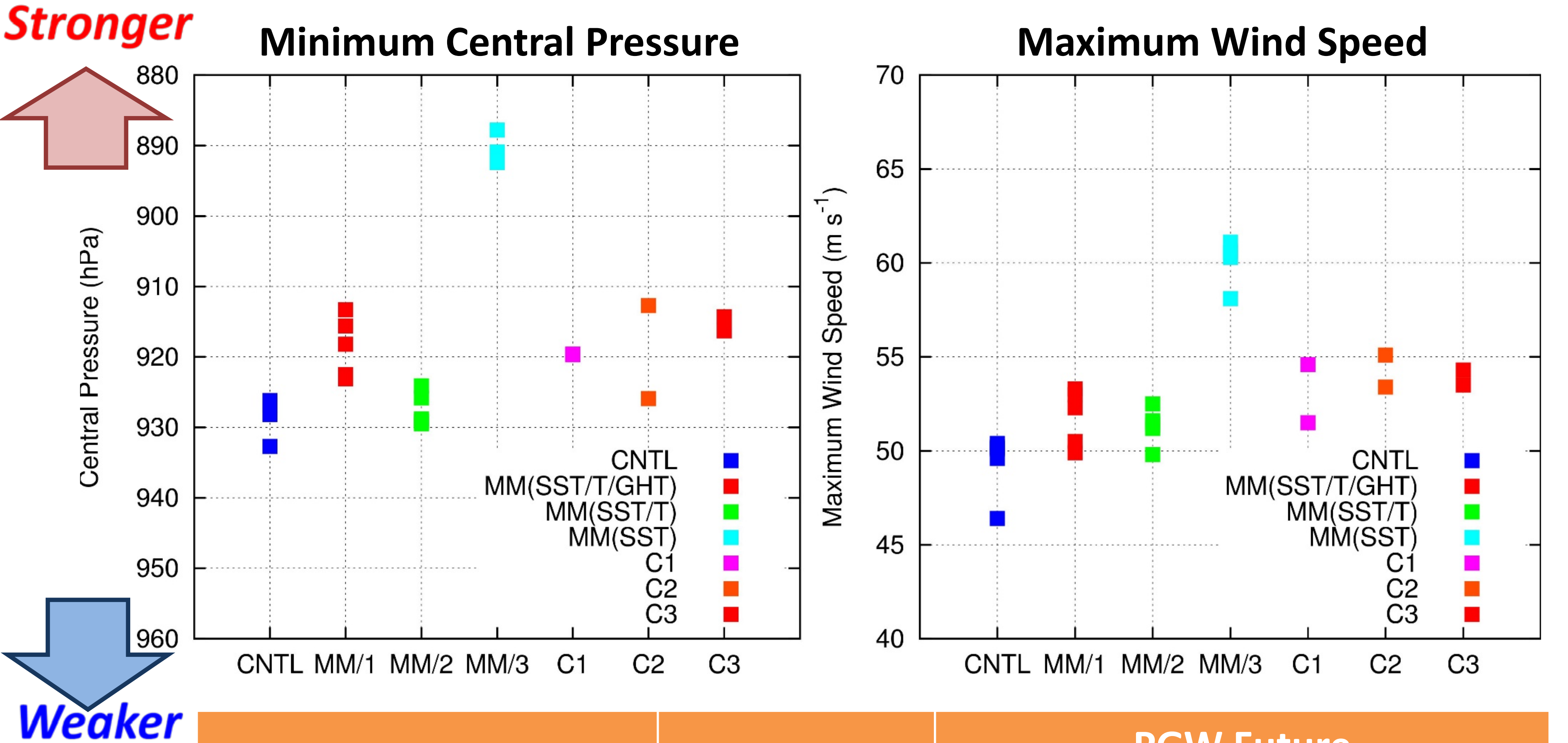



| | Present | PGW Future | |
|---|---|---|---|
| | | SST + 3D atm | SST |
| Min central pressure (hPa) | 899.5 – 909.0 | 879.4 – 898.1 | 859.7 – 876.8 |
| Max wind speed (m/s) | 55.4 – 61.8 | 64.6 – 66.5 | 71.1 – 73.3 |

Cf: In Haiyan case, min central pressure decreases by 6.44 hPa.

# Changes in typhoon intensity at landfall




| | Present | PGW Future | |
|---|---|---|---|
| | | SST + 3D atm | SST |
| Min central pressure (hPa) | 926.2 – 932.7 | 912.7 – 929.5 | 887.8 – 892.4 |
| Max wind speed (m/s) | 46.4 – 50.4 | 49.8 – 55.1 | 58.1 – 61.1 |

# Typhoon disaster in northern Japan

Typhoon Marie (1954) “Toyamaru Typhoon”

- Shipwreck of “Toyamaru” over the Tsugaru Straits: 1139 deaths

Typhoon Mireille (1991)

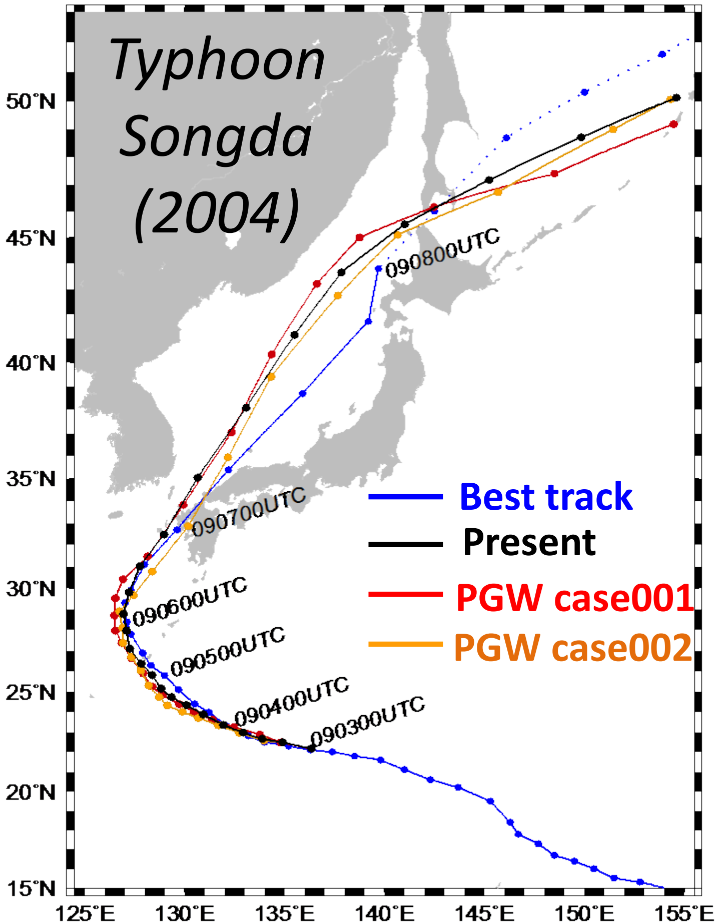
- Significant damages to agriculture (e.g., apple trees in Aomori Prefecture)

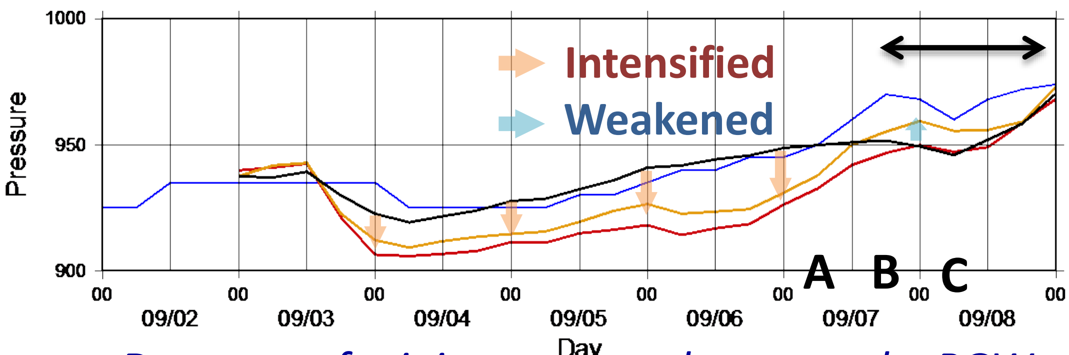
Typhoon Songda (2004)

- Forest damages over Hokkaido

DPRI-KU

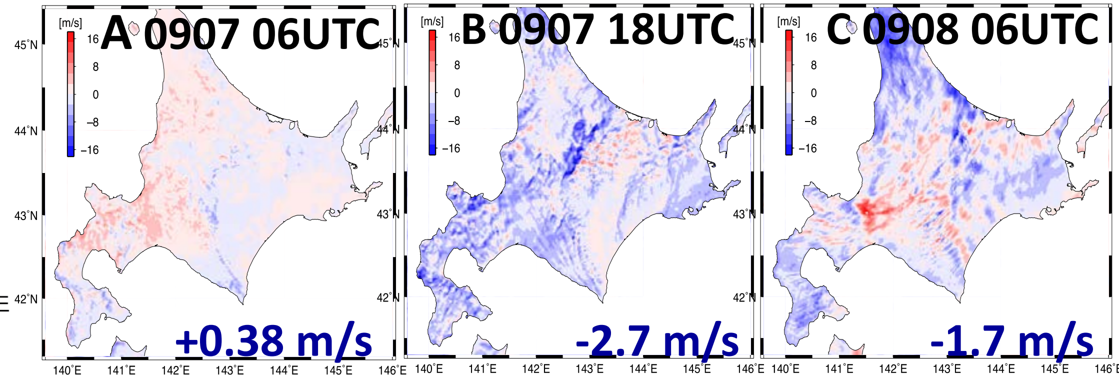
# Changes in typhoon hazard in northern Japan




*Decrease of minimum central pressure by PGW*
*case001: -28hPa; case002: -22hPa*

## Changes in wind speed by PGW

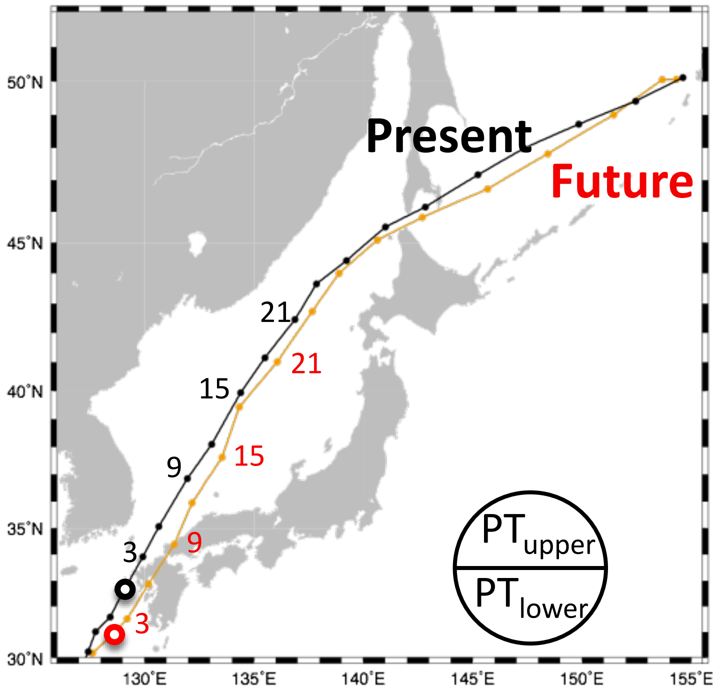


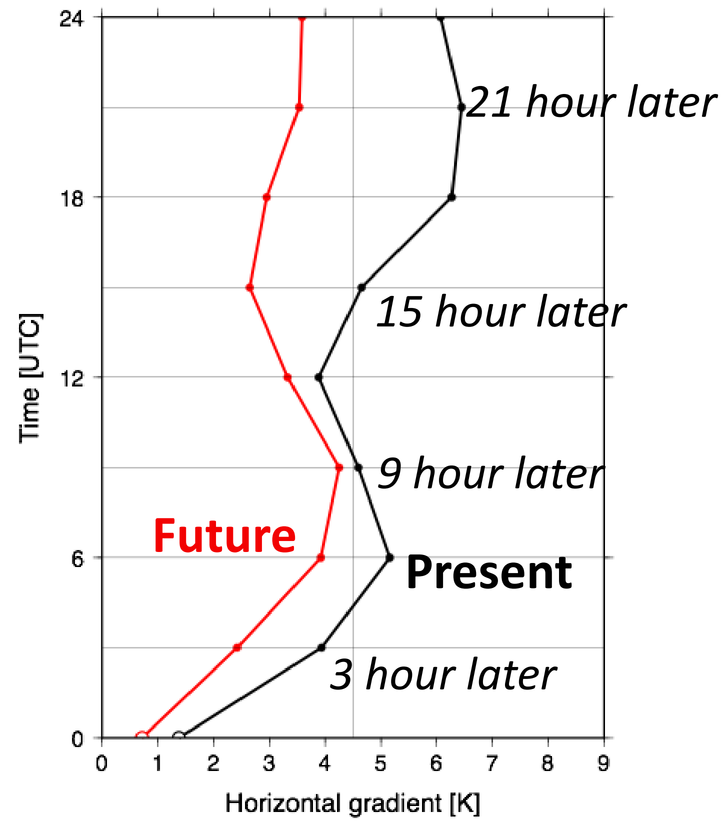

Decrease in wind speeds due to typhoon under PGW condition

(Ito et al. 2016)

# Environmental control on the typhoon change

North-south gradient of temperature along the typhoon track

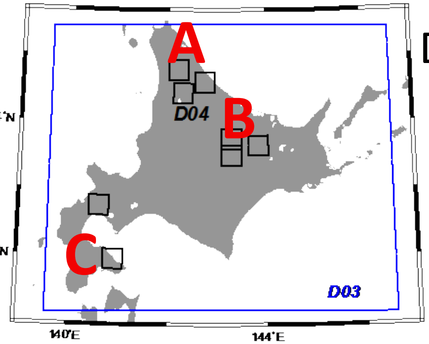



Decrease in the temperature gradient → Decrease in baroclinicity → Reduce the re-intensification due to extratropical transition

(Ito et al. 2016)

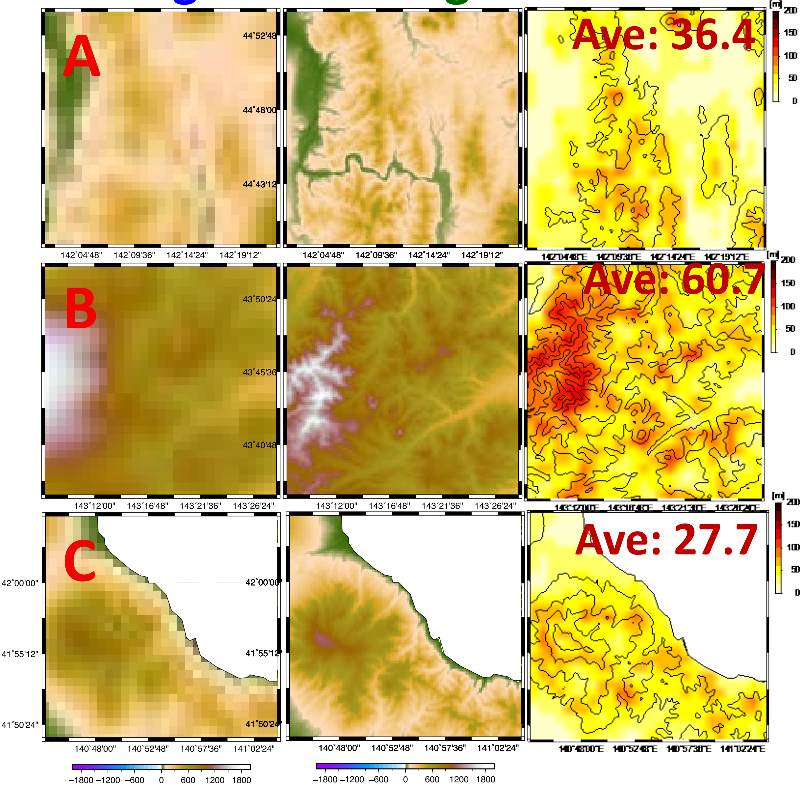
# Added-values in higher-resolution simulations



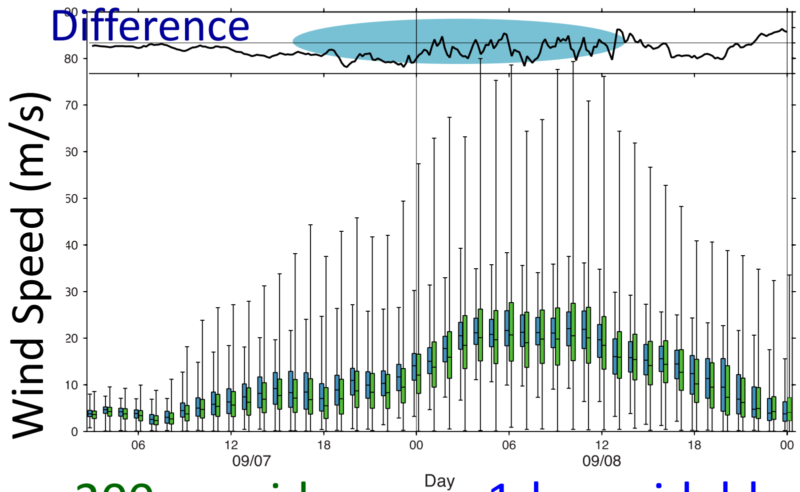

Degree of terrain complexity (Jimenez and Dudhia 2012)

$$\sigma_{sso} = \sqrt{\frac{1}{N_{d04}} \sum_{i=1}^{N_{d04}} (h_i - \bar{h})}$$

1 km grid | 200 m grid | σ

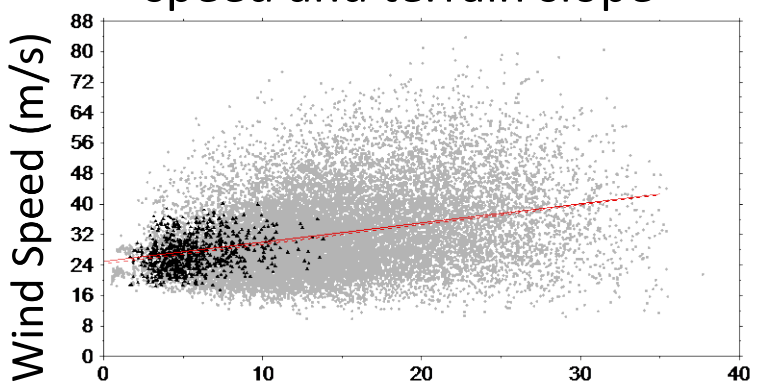



Time series of area-mean and variability of wind speed in Region B




200-m grid: green; 1-km grid: blue

Relationship between wind speed and terrain slope




(Ito et al. 2016)

# Summary

Conduct downscaling numerical experiments of extreme typhoons

Haiyan (2013), Vera (1959), Songda (2004)

Quantitative estimation of the severity of typhoon is important for better assessment of resulting hazards.

Assess impacts of climate change on the severity of typhoons

Pseudo-global experiment is a useful approach to consider how a past extreme typhoon will change under future global warming.

Typhoon hazards under global warming may depend on the latitudinal region

Despite the increased intensity at its mature stage, typhoon may quickly weaken in the northern part of Japan, decreasing the severity of hazard.

# Precise Impact Assessments on Climate Change

Climate change projection contributing to stabilization target setting (JAMSTEC)

Prediction and diagnosis of imminent global climate change (U Tokyo)

**Climate prediction data**

Development of basic technology for risk information on climate change (MRI)

PI: Prof. E. Nakakita (DPRI, Kyoto U)
Kyoto U, PWRI, U Tokyo, Tohoku U, Nagoya U, Hokkaido U

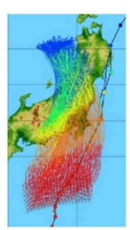
Precise impact assessments on climate change

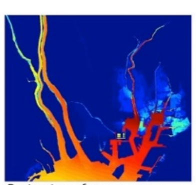
Natural disaster (DPRI, Kyoto U
Water resources (DPRI, Kyoto U)
Ecosystem (Tohoku U)

Projection and Uncertainty of Natural Hazard

Socio-Economic Impact


Future change of river discharge


Super Typhoon

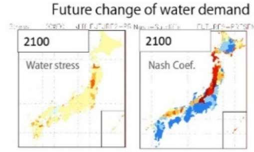

Projection of storm surge

Socio-Economic Impact

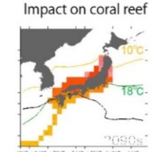
Worst Class Scenario for Natural Harzards

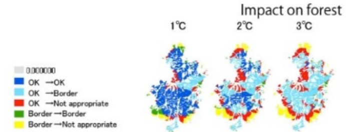
**SOUSEI-D**


Risk for Water Resources



Future change of water demand


Impact on coral reef



Impact on forest

Impact on Ecosystem and Biodiversity

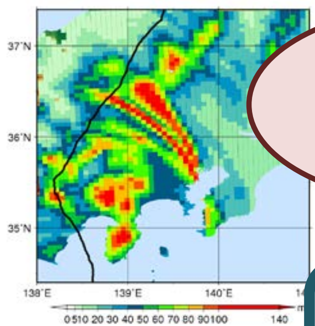
# Risk assessment of meteorological disasters in SOUSEI-D

Climate model output (GCM, RCM) (CMIP5, Kakushin, Sousei)

**Extreme events**

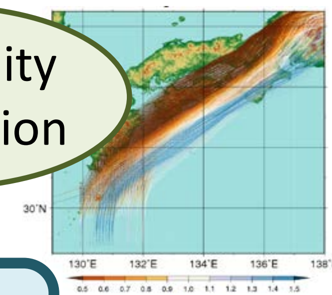
**(Typhoon, rain, wind)**

***Dynamical downscaling***




Worst-case scenario

***Statistical downscaling***




Probability information

Downscaling to regional-scales (river basin, coastal area)

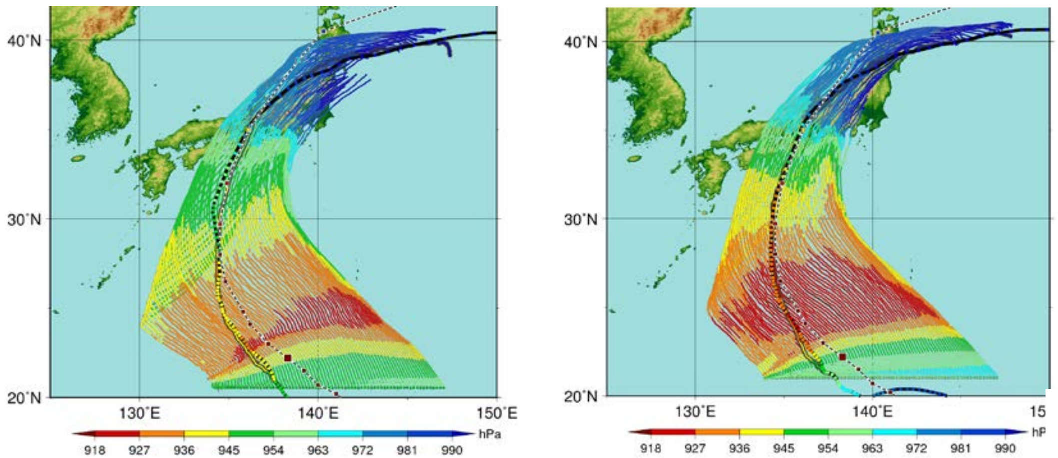
- Sufficient resolution for engineering assessment
- Probability information based on ensemble simulations
- Meteorological disaster risk in worst-case scenarios

Socio-economic impact assessment

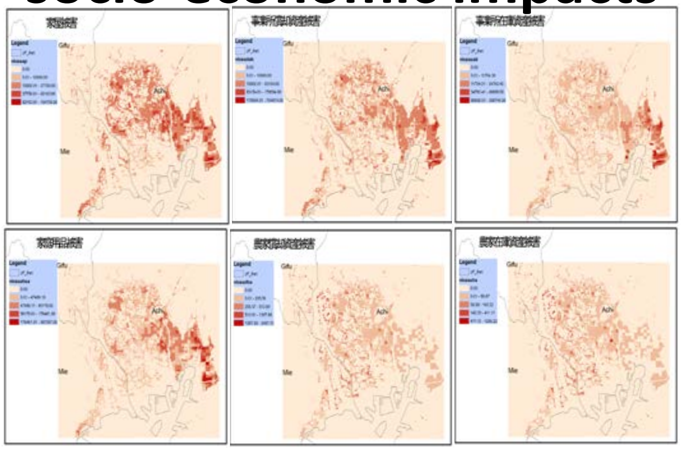
# Impacts on natural disasters/water resources

## Typhoon hazard assessment

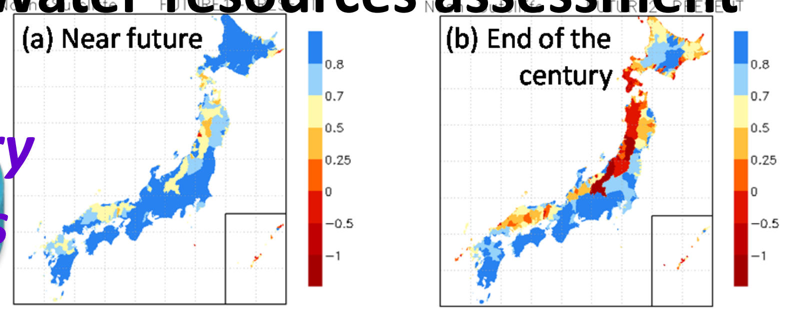
1959 September condition | Future September condition




## socio-economic impacts

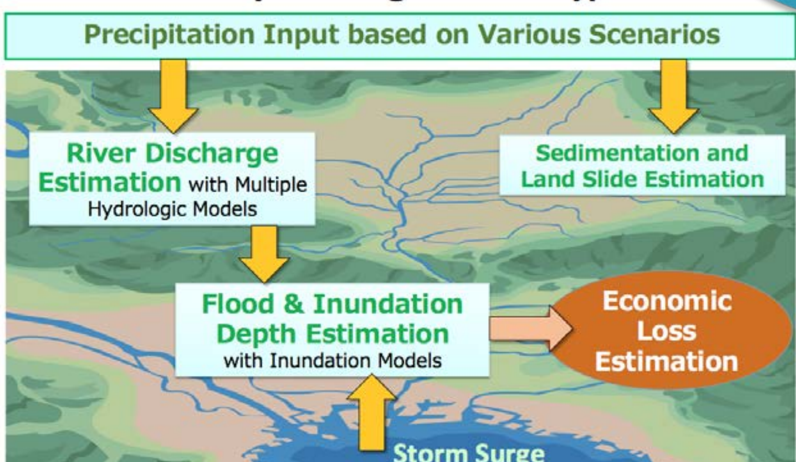


## Water-resources assessment



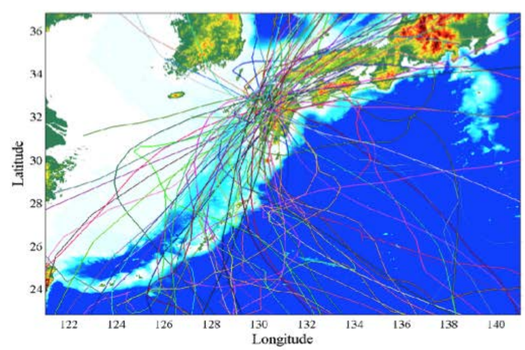

## Water-related disaster assessment

**Comprehensive Economic Loss Estimation Caused by the Largest Class Typhoon**

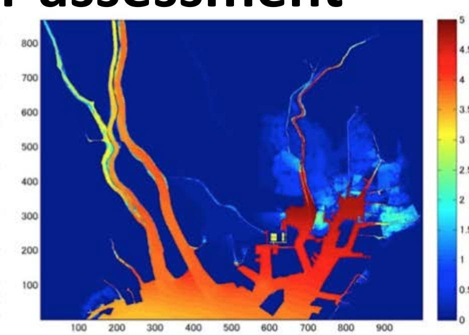



*Interdisciplinary collaborations*

## Coastal disaster assessment




確率台風モデルで計算された台風コース




伊勢湾を対象とした擬似温暖化
＋最悪コース条件下での高潮氾濫